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ABSTRACT

This paper presents a comparison of the most frequently used methods for improving the spatial resolution of images. Several methods have been proposed for the merging of high spectral and high spatial resolution data in order to produce multispectral synthetic images having the highest spatial resolution available within the data set, and close to reality. The methods under consideration are Brovey transform, Intensity Hue Saturation (IHS), Principal Component Analysis (PCA), P+XS (from CNES) and four methods using the ARSIS concept, including the High-Pass Filtering (HPF). The duplication of pixels is also performed, in order to assess the benefits of fusion process. The present communication discusses the methods, their advantages and disadvantages.

1. INTRODUCTION

Several studies and publications have shown that merging broadband high spatial resolution images with low spatial resolution high spectral resolution images proves to be of great benefit in many applications. Many methods have been developed in that purpose and produce multispectral images having the highest spatial resolution available within the data set. They apply on a data set comprising multispectral images B_{il} at a low spatial resolution l and images A_h at a higher spatial resolution h but with a lower spectral content. Examples of such a data set are the SPOT-XS (3 bands, 20 m) and SPOT-P (panchromatic, 10 m) images, or the SPOT-4 case, with 3 bands at 20 m (XS1, XS3, and MIR) and the band XS2 at 10 m.

The number of methods is fairly large. We are only concerned with those methods which claim to provide a synthetic image close to reality when enhancing the spatial resolution, and not those which only provide a better visual representation of the image (e.g., Carper *et al.*, 1990).

The latter are very useful for photo-interpretation. This is particularly true when the number of spectral bands is much larger than the usual three bands for describing colors: red, green, and blue. However, such methods have their limitations, especially with the new space-borne sensors and the most recent techniques, which allow the reconstruction of high spatial resolution landscapes with objects having their natural colors. Here, in this context, natural colors mean the colors that are perceived by the human eye. Examples are the recent commercial space missions (Ikonos, Orbview,), which provide, or will provide, images with high spatial resolution images at 1 m, and three multispectral images at 4 m, taken in the red, green and blue bands. Ikonos has an additional near infrared band at 4 m.

It follows that the topic of our paper is of a larger concern, and actually is of interest to any producer or user of synthetic images resulting from a fusion process.

These methods under discussion in this paper aim at constructing synthetic multispectral images B^*_{ih} having the highest spatial resolution available within the data set (e.g. the 3 XS bands at 10 m in the

case of SPOT 1-3) which are close to reality by performing a high-quality transformation of the multispectral content when increasing the spatial resolution.
This paper presents a comparison of the most frequently used methods for improving the spatial resolution of images. Several aspects are assessed: visual, performances in synthesizing individual spectral images and multispectral sets.

2. THE METHODS UNDER COMPARISON

Eight methods were selected. They are relevant to the three groups of techniques currently used:

- Projection of original data sets into another space, substitution of one vector by the high resolution image and inverse projection into the original space. We selected the IHS (Intensity, Hue, and Saturation) method and the PCA (Principal Component Analysis) method (Carper *et al.* 1990).
- Relative spectral contribution. We selected the Brovey transform (Pohl, van Genderen, 1998) and the CNES P+XS method (Anonymous, 1986). It should be noted that the Brovey transform does not well represent this group because of its poor principles in construction. Nevertheless, it is often used.
- Scale by scale description of the information content of both images and synthesis of the high-frequency information missing to transform the low spatial resolution images into high spatial resolution high spectral content images. The ARSIS concept (Ranchin, Wald, 2000) has developed in several methods. We selected the High-Pass Filtering (HPF) method (Chavez *et al.* 1991), and three models presented by Ranchin and Wald (2000), making use of wavelet transform: Model 1, Model 2 and RWM.

Additionally, we used the duplication technique, in order to assess the benefits of the fusion and to check whether it is worth to implement or use each of the eight techniques relative to a much simpler procedure, for which there is no fusion at all.
The Brovey transform, the IHS and PCA methods were performed using the commercial software ERDAS. The authors have coded the other algorithms.
The HPF filter has been constructed by computing the second derivative of an apodisation function as indicated by Chavez *et al.* (1991). In that case, it is a Laplacian filter, which is applied to the high resolution image, and whose results are added to the low resolution images. The filter is a 3x3 matrix, and the coefficients are:

3. THE PROTOCOL FOR ASSESSMENT

The protocol of Wald *et al.* (1997) is followed to assess the quality of the results of the different methods. The methods are applied to the same SPOT image of the city of Barcelona, Spain, than in their paper (Figure 1). Such an urban area has been selected for illustration because it is certainly the most difficult type of landscape to deal with according to our knowledge. Urban areas often point out the qualities and drawbacks of algorithms because of the high variability of information in space and spectral band, induced by the diversity of features both in size and nature.
In the SPOT case, the multispectral images B_{il} are the XS1, XS2 and XS3 bands at original resolution of 20 m. The high spatial resolution image A_h is the panchromatic band P with a spatial resolution of 10 m. The synthetic bands B^*_{ih} are the XS1, XS2 and XS3 bands synthesized at 10 m. Table 1 gives the means, standard-deviations and calibration coefficient of the original images.

	XS1	XS2	XS3	P
Mean	58	48	55	53
Standard deviation	12	15	9	15
Calibration coefficient	1.2181	1.22545	1.29753	1.39198

Table 1. Means, standard deviations, and calibration coefficients of original images (in W m^{-2} st^{-1} μm^{-1})

The merging methods under concern aim at constructing synthetic images B^*_{ih} close to the reality. Wald *et al.* (1997) established the properties of such synthetic images:

- Any synthetic image B^*_{ih} once degraded to its original resolution l: $(B^*_{ih})_l$, should be as identical as possible to the original image B_{il}.
- Any synthetic image B^*_{ih} should be as identical as possible to the image B_{ih} that the corresponding sensor would observe with the highest spatial resolution h.
- The multispectral set of synthetic images B^*_{ih} should be as identical as possible to the multispectral set of images B_{ih} that the corresponding sensor would observe with the highest spatial resolution h.

Wald *et al.* also propose a protocol to check whether a fused product meets these properties. For each property, a visual inspection of the fused product is performed first and compared to the ideal product. It shows the major drawbacks of a method. These drawbacks can be quantified by a quantitative assessment of the discrepancies between the fused product and the ideal one.

Figure 1. SPOT P image of Barcelona used for test. The dark area in the upper left corner is the slope of a hill with Mediterranean vegetation. The size is 512x512 pixels. Copyright CNES-SPOT Image (1990).

To assess the first property, the synthetic image B^*_{ih} made at 10 m are filtered before resampling to degrade the resolution down to 20 m: $(B^*_{ih})_l$. They are then compared to the original images B_{ih}. The filtering function is a sine cardinal (sinc) kernel truncated by a Hanning apodisation function of size 13x13.
To test the second and third properties, the P and XS images are degraded to a resolution of 20 (A_{2h}) and 40 m ($(B_i)_{2l}$), respectively. Then, images B^*_{il} are synthesized at a 20-m resolution and compared to the original XS images B_{il} by a visual inspection on the one hand, and by performing a difference pixel per pixel. The discrepancies are analyzed and synthesized in five sets of criteria, which deal respectively with:

- each spectral band in a global way,
- the statistical distribution of errors at pixel level for each spectral band,
- information correlation between the different spectral images,
- the multispectral aspect, that is the errors in reconstructing spectral signatures,
- the reconstruction of the most frequent spectral signatures.

Wald *et al.* discussed the extrapolation of the quality assessments made at 20 m to 10 m. They underlined the unpredictability of such assessments when changing the resolution. That is, it cannot be said whether the error at 10 m is larger or lower than that at 20 m. By testing several methods on SPOT images degraded to 40 and 80 m, they found in several cases that the quality was best at 20 m than at 40 m. They suggested that one can assume that the quality of the synthetic images at 10 m may be considered as similar to that of the synthetic images at 20 m.

4. COMPARISON OF THE METHODS

A visual inspection of the synthesized images B^*_{ih} is performed first, once the contrast table adjusted for each. They are visually fairly close one to the others for all methods and of satisfactory quality, except for the IHS method which produces in that case an image of bad quality in the XS3 band. The HPF images contain too much high frequencies: the contours are enforced in an excessive manner. Of course, the images resulting from the duplication technique exhibit less small details than the other images.

First property

Like the B^*_{ih} images, the contrast-adjusted different $(B^*_{ih})_l$ images are visually fairly close and of satisfactory quality, except for the IHS method in the XS3 band, the HPF and the duplication images. Adjusting the contrast table for each $(B^*_{ih})_l$ accommodates for linear changes in statistical distribution, and especially mean and variance. For the Brovey, IHS and PCA methods, these parameters are strongly modified relative to the original B_{il} images.

The details of the quantitative comparison (not shown here) further demonstrate that the first property is clearly not satisfied by the Brovey, IHS and PCA methods, and also the P+XS method. In these four methods, the synthesis of the band B^*_{ih} at 10 m is influenced by the high resolution image A_h and the other spectral bands B_{jl}. This influence is irrespective of the size of the structures, that is that the large structures (*i.e.* larger than 20 m) observed in these images A_h and B_{jl} are partly included in the synthesized image B_{ih}. A mathematical analysis of these methods clearly shows that the influence of A_h and the other spectral bands B_{jl} in the synthesized image B^*_{ih} does not disappear when reducing the resolution to 20 m.

The methods built within the ARSIS concept using the wavelet transform as well as the duplication technique are inherently built to satisfy this first property, with reservations regarding the degradation process as discussed by Wald *et al.* (1997). On the contrary, the HPF technique does not satisfy this property, mostly due to a strong change in variance. This is confirmed by a visual inspection.

Second property

The conclusions of the visual analysis of the different B^*_{il} images are in accordance with that obtained for the first property.

Compared to the first property, we found that the testing of the second property enhances the drawbacks of a method. This is why we put an emphasis on this comparison. Tables 2 to 4 provide some statistics on the differences between the original B_{il} images XS1, XS2 and XS3 at 20 m and the synthesized B^*_{il} images. They provide a global view of the quality of a method to synthesize each individual spectral band B_i.

These tables show a very strong bias (difference between mean values) for the Brovey transform for the three bands. This bias amounts to approximately 0.65 times the original mean value. This is due tot he very construction of this transform, which, briefly, written, is equal to the spectral band under concern, multiplied by the ratio of three times the panchromatic band P and the sum of the three bands. Since the method does not request the computation to be made in radiances, a difference in mean between spectral bands - as here between XS2 and the others (Table 1) - may induce a strong bias for all synthesized bands. This construction also implies that the variance of a synthesized band B^*_{il} is a combination of the variances of all bands, including the panchromatic. It follows that the variance of the B^*_{il} image strongly differs from that of the original image B_{il}. This method adds too much variance by a relative amount exceeding 70 % of the original variance. The correlation between the B_{il} and B^*_{il} images is high as far as the correlation between the B_{il} and A_h images is high. The correlation between XS3 and P is only 0.35 instead of 0.97 for the two other bands, and the correlation between XS3 and $XS3^*_{20}$ is only 0.7, which is rather poor. Finally the relative error at pixel level in reconstructing the original image ranges from 10 to 17 % (standard deviation).

As a whole, the other methods perform better, though only a few provide satisfactory results. The IHS method exhibits a relative negative bias of 10 %, which is still too large and means an overestimation of the values as a whole. This bias may be partly overcome by an *a priori* equalization of the dynamics of the images B_{il} and A_l. This would also reduce the differences in variance, and more generally would provide better results if the correlation between the images B_{il} and A_l were large. This equalization step is made at the expenses of the physical significance of the images. This remark also holds for the PCA and the HPF methods.

The IHS method does not introduce enough high frequency signal in the synthesized image (the variance is too low), contrary to the PCA method, for which the variance is too large, except for the XS3 band.

The PCA method performs slightly better than the IHS method as a whole, but is far from being satisfactory. It should be noted for these two substitution methods that the results are strongly dependent upon the original images. According to the mutual correlation between bands and the variance in each band, the introduction of high frequencies will be either too large or too low, and sometimes satisfactory. This is true for the other parameters under examination for this second property.
The P+XS method is unbiased but introduces too much signal from the P band into the XS*1 and 2. This method reduces to duplication for the XS3 band. Accordingly the variance of the XS*3 image is too low: there is no fusion and no addition of signal from another source.
The HPF method is rather disappointing. The amount of excessive variance is huge. All the contours are enforced but excessively. The correlation between the synthesized and original images is low for all bands. Finally the error at pixel level is extremely high.
Compared to the previous methods, the duplication technique performs better though it does not call upon any fusion process. Of course, these images do not exhibit as much details as the others, but if quantitative measurements are at stake, one may legitimately prefer a duplication technique to most of the above mentioned methods, especially when considering the extra resources requested.
The best results are attained by the methods using the wavelet transform. The three methods offer the same level of quality for the bands XS1 and XS2. For XS3, the Model 1 exhibits lower quality. In this model, the high frequencies of the P image, expressed in wavelet coefficients, are added to the XS3 band after histogram equalization. As said before, the correlation coefficient between the XS3 and P images is low (0.35); this coefficient characterizes the similarity in small size structures between the images. Accordingly, the P wavelet coefficients do not represent the actual corresponding XS3 wavelet coefficients; the correlation coefficient in Table 4 is fairly low (0.89) and the synthesized variance is too large.
Finally it should be noted that the results are better for the bands XS1 and XS2 than for the band XS3. This is due to the fact that the band P encompasses the bands XS1 and XS2 and not the XS3. Most of the methods cannot cope with this. Only the two methods, Model 2 and RWM, are capable of producing satisfactory results in this case.

Third property

Color composites have been created for each synthesized set of multispectral B^*_{il} images. The color coding for each set follows that used for the original set, in order to make them comparable and following the recommendations of Wald *et al.* (1997). Unsurprisingly, the color composite obtained by the Brovey transform does not show similarity with the original one. This also holds for the IHS method but to a lesser extent. The other methods provide color composites closer to the original with various degrees in quality, which are better described through some quantitative parameters.
Table 5 shows the performances of each method in synthesizing the multispectral information. It represents the difference between the actual number of triplets and the number found in the synthesized images for each method. These triplets may be different from the original ones; only their number is taken into account in this table. The number of original triplets is approximately 45,600 and is large compared to the number of pixels. This demonstrates the spectral diversity of urban areas.
The Brovey transform only found approximately 8,000 triplets! It means that this transform flattens out the spectral diversity of a scene. The HPF method does not perform correctly for this parameter; it provides about twice more triplets. This is due to the enforcement of structures already noted. As expected, the duplication exhibits fewer triplets than the original. The high discrepancy (49 %) demonstrates the changes in the statistical distribution of spectral signatures when changing the spatial resolution. The other methods perform from fairly correctly (P+XS) to very satisfactory (Model 2).
Actually, this table 5 partly summarizes the multispectral performances of each method. Most of the triplets have a low frequency, i.e. most of them are carried by a very few number of pixels. The average number of pixels per triplet is 5.7. Many of the triplets are superfluous; they are carried by 1 or 2 pixels

and are not taken into account in further classification processes, or visual analysis of the synthesized images as colored composition.
Table 6 shows the performances of each method in synthesizing the most frequent actual triplets. Each triplet under consideration has a frequency of at least 0.01 percent, which corresponds to 26 pixels in this case. The total of pixels they represent amounts to 23 percent of the total number of pixels in the image. Hence synthesizing them accurately is of primary importance in classification purposes. In this Table, for each of these triplets, the number of pixels carrying this triplet in the synthesized images is compared to the corresponding number in the original images. The differences are summed up for all the triplets, giving the "difference with original" in Table 6. A difference equals to 0 means that all the predominant triplets are exactly the same than in original images. Because of its bias in all bands, the Brovey transform is unable to retrieve any of these 1,675 triplets. Very bad results are also obtained by the IHS method: it retrieves only 721 triplets (43 %) and only 12 % of the corresponding pixels. It means that it does not synthesize correctly the triplets and even for those it retrieves, they are not correctly allotted to the pixels: this would induce errors in cartography after classification. This bad result is not contrary to Table 5, for which synthesized triplets and actual triplets may differ: only the numbers of triplets are compared.
The other methods provide more satisfactory results. This means that each of these methods is capable of synthesizing the predominant spectral signatures. If a classification is made by using only the spectrum, these methods will provide the same number of classes. However, for most of the methods, the size of the classes will differ from original. The HPF method only retrieves 52 % (i.e. the half) of the total number of pixels belonging to these predominant classes. It follows that the resulting map may be fairly inaccurate, except if, by chance, class aggregation processes overcome this drawback. The P+XS method is also inaccurate: 41 % of pixels are missed. The PCA performs better but is still of low accuracy. The duplication technique and the Model 1 obtain very good results. The RWM and the Model 2 achieve excellent results: all the triplets are exactly retrieved and the number of retrieved pixels carrying one of these triplets in both the original and synthesized images is almost exactly the same. This ensures on the one hand a good classification, and on the other hand a good accuracy in mapping from this classification.

5. CONCLUSION

We recall that we have dealt with the multispectral aspects of the synthesis in this paper. In accordance with the protocol of Wald *et al.* (1997), other aspects may have been considered, such as spatial gradients, forms and structures, in each spectral band and in the multispectral set. Such aspects and the corresponding criteria are of high importance in several applications such as the automatic recognition of the network of the streets (Couloigner *et al.* 1998). They have not been considered here.
From the previous section, we have ranked the methods, which are now briefly discussed from the worst to the best. The conclusions drawn from this example have been validated for several other cases by the authors and are supported by other authors (Chavez *et al.* 1991; Mangolini *et al.* 1993; Munechika *et al.* 1993; Terretaz 1997; Ranchin, Wald 2000; Raptis *et al.* 1998; Wald *et al.* 1997; Wiemker *et al.* 1998; Zhou *et al.* 1998).
Brovey transform. The Brovey transform is not relevant at all, mostly because there is a strong bias error due to its very construction. Though it can be partly corrected, it will never reproduce the spectral content in an accurate way, except in rare cases.
ARSIS, HPF method. The authors are actually disappointed by the HPF method. As a possible implementation of the ARSIS concept (Ranchin, Wald 2000), they were expecting much better results. As expected from this concept, the bias is close to 0. However too much variance is introduced in the synthesis and this leads to an excessive enforcement of contours as well as to a low correlation coefficient with original. The quality of the synthesis of the predominant triplets is bad: though all these triplets are retrieved, about half of the pixels carrying these triplets are missing.

IHS method. The IHS method often produces nice-looking results but not always as in this case. The results are of poor quality: the bias is high, not enough details are injected (likely due to not taking into account calibration coefficients), and correlation coefficient is low, especially in band XS 3. Furthermore it strongly distorts the spectral content of the synthesized images. Wiemker *et al.* (1998) find that the IHS results are inferior to results obtained from the relative spectral contribution method.
PCA method. The PCA method also produces nice-looking results. It can apply in a more general fashion compared to the IHS method. It also performs much better, especially for the XS 3 band. The bias is small, but too much structures of P band are injected into the XS 1 and 2 bands. The synthesis of the predominant triplets is acceptable. Accordingly it may be recommended instead of the IHS. It should be underlined that such projection-substitution-projection techniques usually deliver products of inconstant quality.
Duplication technique. Surprisingly the duplication method provides fairly good results though it does not call at all on the high resolution image. Wald *et al.* (1997) underlined that this method may be preferred to the P+XS method on a case to case basis, e.g., if the synthesis of the most predominant triplets and associated pixels is central in the application.
CNES P+XS method. The P+XS method, from CNES, is limited to the SPOT case. Belonging to the relative spectral contribution group of methods, it performs better than the projection-substitution-projection techniques. Results are not satisfactory. Of course, it performs like duplication for the XS 3 band, i.e. rather poorly. For the other bands (XS 1, XS 2) encompassed by the panchromatic band P, the results are not good. It introduces too many high frequency signals in the synthesized images. Finally the frequencies of occurrence of the predominant triplets are badly synthesized (42 % missing in total). However the effective visual enhancement performed by the P+XS method may be recognized.
ARSIS, Model 1 method. The three methods using the ARSIS concept with wavelet transform provide similar results, which are of good quality and fairly close to the ideal values. ARSIS Model 1 (identity) does not perform so well for XS 3 band because it does not take into account the spectral behavior of the small-size structures, which are set up equal to those of the P band in this model.
ARSIS, Model 2 and RWM methods. ARSIS Model 2 and RWM methods perform the best. They achieve very good quality products. The quality of the synthesis of the predominant triplets is impressive. Another striking feature compared to the other methods is that they are capable of achieving good results for the XS 3 band. All published comparisons show that the ARSIS concept, combined with the wavelet transform and the multiresolution analysis leads to the best presently achievable results.
Our final conclusion is that only a very few methods achieve satisfactory results (Model 2, RWM). On the one hand, further investigations are needed to improve these two methods or to design new ones that perform better. On the other hand, further work should verify that these two methods could enter a production system delivering fused products with a controlled quality.

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	Brovey	IHS	PCA	P+XS	HPF	Duplication	ARSIS Model 1	ARSIS Model 2	ARSIS RWM
Bias (ideal value: 0)	36.90	-5.85	-2.13	0.35	0.35	-0.01	0.00	0.00	0.00
relative to the mean XS value	64 %	-10 %	-4 %	1 %	1 %	0 %	0 %	0 %	0 %
Actual variance-estimate (ideal value: 0)	100	32	-67	-50	-587	10	-6	-4	7
relative to the actual variance	70 %	22 %	-47 %	-35 %	-420%	7 %	-4 %	-3 %	5 %
Correlation coefficient between XS and estimate (ideal value: 1)	0.97	0.92	0.98	0.97	0.66	0.94	0.98	0.99	0.99
Standard-deviation of the differences (ideal value: 0)	5.9	4.8	3.8	3.8	21.1	4.0	2.2	2.1	1.9
relative to the mean of XS value	10 %	8 %	7 %	7 %	36 %	7 %	4 %	4 %	3 %

Table 2. Some statistics on the differences between the original and synthesized images, in radiance (W m^{-2} st^{-1} μm^{-1}) or relative value, for XS1 band.

	Brovey	IHS	PCA	P+XS	HPF	Duplication	ARSIS Model 1	ARSIS Model 2	ARSIS RWM
Bias (ideal value: 0)	30.60	-4.58	-2.81	0.26	0.26	0.00	0.00	0.00	0.00
relative to the mean XS value	64 %	-10 %	- 6 %	1 %	0 %	0 %	0 %	0 %	0 %
Actual variance-estimate	172	31	-113	-42	-597	12	-11	-8	7
relative to the actual variance	77 %	14 %	-51 %	-19 %	-267 %	5 %	-5 %	-3 %	3 %
Correlation coefficient between XS and estimate (ideal value: 1)	0.98	0.96	0.98	0.98	0.71	0.96	0.99	0.99	0.99
Standard-deviation of the differences (ideal value: 0)	8.1	4.0	4.9	3.1	20.7	4.4	2.6	2.3	1.9
relative to the mean of XS value	17 %	8 %	10 %	6 %	43 %	9 %	5 %	5 %	4 %

Table 3. As Table 2, but for XS2 band.

	Brovey	IHS	PCA	P+XS Duplication	HPF	ARSIS Model 1	ARSIS Model 2	ARSIS RWM
Bias (ideal value: 0)	35.50	-5.49	-0.42	0.00	0.22	0.00	0.00	0.00
relative to the mean XS value	65 %	- 10 %	1 %	0 %	0 %	0 %	0 %	0 %
Actual variance-estimate (ideal value: 0)	67	46	7	9	-47	-14	-4	8
relative to the actual variance	81 %	55 %	8 %	11 %	-57 %	-17 %	-5 %	9 %
Correlation coefficient between XS and estimate (ideal value: 1)	0.69	0.78	0.92	0.91	0.48	0.89	0.92	0.95
Standard-deviation of the differences (ideal value: 0)	7.0	5.8	3.6	3.8	20.8	4.5	3.7	2.7
relative to the mean of XS value	13 %	11 %	6 %	7 %	38 %	8 %	7 %	5 %

Table 4. As Table 2, but for XS3 band. For XS 3, the method "P+XS" reduces to duplication

	Original	Brovey	IHS	PCA	P+XS	HPF	Duplication	ARSIS Model 1	ARSIS Model 2	ARSIS RWM
Number of triplets	**45 618**	7 965	41 052	47 594	53 162	86 700	23 276	47 962	45 438	43 918
Difference with original	-	37 653	4 566	-1 976	-7 544	-41 082	22 342	-2 344	180	1 700
(in %)		83 %	10 %	-4 %	-17 %	-90 %	49 %	-5 %	0 %	4 %

Table 5. Performances in synthesizing the multispectral information. Difference between the actual frequency of a triplet (XS1, XS2, and XS3) and the estimates. Average number of pixels per triplet is 5.7.

	Original	Brovey	IHS	PCA	P+XS	HPF	Duplication	ARSIS Model 1	ARSIS Model 2	ARSIS RWM
Number of predominant triplets	**1 675**	0	721	1 673	1 671	1 675	1 675	1 675	1 675	1 675
Difference with original (ideal: 0)	-	1675	954	2	4	0	0	0	0	0
(in %)		100 %	57 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Number of pixels	**60 372**	0	6 961	52 186	35 864	28 849	61 916	53 876	60 002	60 195
Difference with original (ideal: 0)	-	60 372	53 411	8 186	24 508	31 523	-1 544	1 996	370	177
(in %)		100 %	88 %	14 %	41 %	52 %	-3 %	3 %	1 %	0 %

Table 6. As Table 5 but only the most frequent triplets are taken into account. Each triplet has a frequency of at least 26 pixels (0.01 percent of the total number). The total of pixels they represent amounts to 23 percent of the total number of pixels in the image.